International Journal of Trend in Scientific Research and Development (IJTSRD)
Volume 7 Issue 2, March-April 2023 Available Online: www.ijtsrd.com e-ISSN: 2456 – 6470

Control of Hybrid AC/DC Micro Grid Involving Energy Storage, Renewable Energy and Pulsed Loads

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ABSTRACT

Electricity, a remarkable scientific gift to humanity, has fuelled a civilization where it is utilized for myriad purposes. Nevertheless, a paradigm shift is underway in recent times, transitioning from small generating units to large generating plants connected to distribution systems in the form of renewable energy-powered micro grids. Reactive power in networks has different alignment and efficiency based on the power factor and setup stage. These rows can be classified as passive networks of independent variables based on the sequence inductance and shunting power of the rows. The reactive power flow does, however, have a number of drawbacks. By raising the attracted line at the same charge rate, it effectively lowers the attracted line's efficiency, service, and costs. This also decreases the proportion of energy stabilization. This article presents the modeling of hybrid micro grids for power system configuration performed in the MATLAB/SIMULINK environment. The present work mainly covers the network operation mode of hybrid network. Models have been developed for all converters to maintain a stable system under various load and source conditions, and the control mechanism has also been studied.

KEYWORDS: *Renewable Energy Sources, Hybrid AC/DC Micro grid, Energy Management System*

How to cite this paper: Dr. Shailendra Verma | Abhishek Janghel | Ashish Dewangan | Prashant Bawane "Control of Hybrid AC/DC Micro Grid Involving Energy Storage, Renewable Energy and Pulsed Loads" Published in International Journal of Trend in Scientific Research and Development (ijtsrd), ISSN: 2456-6470, Volume-7 | Issue-2, April 2023, pp.820-827, URL: www.ijtsrd.com/papers/ijtsrd55153.pdf

IJTSRD55153

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INTRODUCTION

The following microgrid definition was created by the US Department of Energy (DOE)."A microgrid is a small-scale electrical network. It provides DER integration with a local load. It offers flexibility to grid disruptions by operating in islanding or grid mode and strong dependability. The necessary for the application in this distribution system was a location with a critical load and a limited electrical supply and delivery protection and economic expansion. A distribution network containing DER (such as solar panels, fuel cells, micro turbines, etc.), energy storage (such as batteries and capacitors), and loads makes up a microgrid. If the system is unplugged from the grid or linked to another system, it can still function independently. If correlated and maintained well, the network's micro sources operation can improve system performance. Maintaining energy utilization is critical in order to save more energy for future generations. Several research in this sector are now underway, however they are only relevant on a limited scale. Consider encouraging data and understanding when a variety of ways might be used.

H. Nikkhajoei et al. identifies improved energy constancy, increased durability, and high energy density through the utilization of surplus heat are among the benefits of DERs. It is an intriguing potential from the standpoint of ecological sustainability, as it produces less emissions. It also benefits the power utility by lowering grid interference, generation and transmission requirements, as well as resources like voltage control and energy storage. Microgrid is the embedded gadget. It is critical to integrate microgrid-connected DERs. The effective and precise management, categorization, and regulation of DERs is also a problem [1]. S Bose et al. proposes that the rise of distributed generating systems is faster than it has been in recent years, owing to greater operational performance and lower emission rates. Photovoltaic panels, batteries, micro turbines, and fuel cells are examples of distributed generators that use a variety of micro-sources to operate. DGs support peak output during peak load hours and standby generation during device shutdowns when energy costs rise. Microgrids

are built by combining a number of modules and parallel distributed generating systems in a specific region. Microgrids feature a wide range of power capabilities and more control adaptability, ensuring system stability and power efficiency [2]. Chi Jin et al. proposes the interaction with the pressures created by producing units and each other establishes a new paradigm for distributed generator utilization without needing major upgrades to the old distribution network's control method. The latter way corresponds to the micro grid's definition. There are several advantages to implementing a microgrid. The microgrid is capable of successfully combining distributed energy infrastructure with loads. Microgrids are referred to as "grid-friendly bodies" since they do not need to be modified in order to provide undesirable electricity, i.e., the distribution grid operating policy. It may also work independently in the event of a mistake [3]. Y. Zoka et al. approaches to improve measurement accuracy, a mentorship and plug-and-play system is used with any portion of the microgrid. The peer-to-peer principle ensures that the microgrid continues to function even if a component or generator fails. The plug-and-play feature allows a device to be connected to the electrical grid at any point before the functions are re-engineered, reducing the danger of technical faults [4].

Anant Naik et al. recommends combining three major strategies that were utilized to create the current reference. Under safe and unpredictable feed voltage conditions, the results are obtained using these three approaches for the same setup. Active power blocking via shunting is effective, and the effectiveness of these systems is mostly determined by the control methods employed to generate electricity comparison. To model and simulate the various device components, MATLAB / Simulink is utilized [5]. Xiong Liu et al. deals with power electronic converters' rapid response solutions, which provide a very steady power supply as well as effective disruption sorting. The use of power electronic converters eliminates two significant issues with DC systems: steady AC/DC/AC conversion and DC current interference under both normal and abnormal situations [6]. Mesut E. Baran et al. proposes that the DC voltage signal is controlled as a result of the cooperative functioning of the power supply coupled to the DC grid. The DC grid system operates in a stand-alone-mode when an AC utility line experiences irregular or failure conditions, and the induced energy is distributed to the loads connected to the DC grid. The DC grid can balance changes in generated electricity and energy absorbed by the load as a chunk of power. System expenses and losses are reduced since just one AC grid coupled inverter is required [7]. P. Piagi et al. approaches to the fact that microgrid is a viable method for adding large amounts of micro generation without affecting the energy network's function. In the event that the present system fails, the microgrid may potentially rejoin and continue to function independently, improving the user's voltage stability [8]. Bhim Singh et al. discusses the topologies, state-of-the-art, performance, technological considerations, future evolution, and prospective applications for improving power quality. The goal of this research is to provide a thorough overview of DSTATCOMs for academics, technicians, and the general public interested in improving power quality. For rapid comparison, a classified database of selected current research publications is also available [9].

M. F. Shousha et al. proposes a time-space wave tracking system based on the p-q principle and a suitable line sensor to tackle the problem of shunting efficient energy amplifiers (SAPF) in non-ideal hands. The enhanced formula uses smaller computations than the standard p-q hypothesis. As a result, a digital signal processor may easily implement this technique (DSP). Three monitoring approaches are compared to the suggested approach: Instant Reactive Power Theory (IRPT), Synchronous Reference Frame (SRF), and Synchronous Detection Method (SDM) [10]. M. Barnes et al. approaches that the micro grid's service looks to be incredibly scalable, integrated, and simple to operate in either connected or islanded grid mode. The islanded mode of service will be enabled for more accommodating capacity usage if the power system is not significantly bigger or is genuinely stopped due to the presence of a fault [11]. R. H. Lasseter et al. identifies generation and related loads as a subsystem and offers a device solution, i.e. a microgrid, to recognize the growing capacity of power generating. This technique eliminates the requirement for central deployment by requiring local distributed generation control. This program allows machine's productivity to double. Demand sources, planned islanding approvals, and the usage of useable heat energy from power producing systems are all required for the current microgrid implementation [12]. F. Katiraei et al. proposes techniques to better understand the usefulness of small-scale distributed producers, such as the ability to deliver waste heat throughout the demand cycle from a grid standpoint, microgrid is an intriguing option since it recognizes that the country's energy system is extensive, antiquated, and only slowly improving. This concept enables for widespread adoption of distribution generation

without requiring a complete overhaul of the distribution network [13-14]

This article presents the modeling of hybrid micro grids for power system configuration performed in the MATLAB/SIMULINK environment. The present work mainly covers the network operation mode of hybrid network. Models have been developed for all converters to maintain a stable system under various load and source conditions, and the control mechanism has also been studied. MPPT algorithms are used to optimize power utilization from DC sources and to coordinate power exchange between DC and AC grids. Although hybrid networks can reduce the DC/AC and AC/DC conversion processes to a single AC or DC network, there are many practical problems for the implementation of hybrid networks based on current AC-dominated infrastructure.

Proposed Model

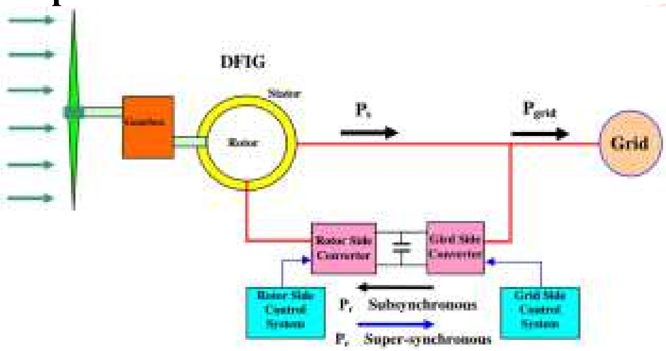

Figure 1 Schematic of the variable speed wind system

A schematic of a variable speed wind system (WECS) is shown in Figure 1. Double feed induction generators (DFIG) have the stator phase windings connected directly to the grid, while the rotor phase windings are connected to a bidirectional power supply. Converter via slip rings. The bidirectional power converter consists of two converters, ie a grid-side converter and a rotor-side converter, and a DC link capacitor placed between the two converters. The main purpose of the line side converter is to keep the intermediate circuit voltage variation low. Since grid-side converters and rotor-side converters can operate in bidirectional mode, the DFIG can operate in either sub-synchronous speed mode or super-synchronous speed mode. Here, the speed limit for DFIG is approximately ±30% of the synchronous speed [10]. In this work, the DFIG model with variable speed wind turbine was developed in Matlab/Simulink environment.

The literature mentions a variety of harmonic compensating strategies. For these kinds of delicate networks, an optimization method is offered by the micro-grid (MG) idea. The process will be made more seamless by hybrid generating technology, which will lessen disruptions brought on by PV and wind power's erratic availability. When the micro-grid has an excess, power exchange with the electricity network is also an option.

With greater penetration of wind energy into the power system, DFIG wind turbines are installed mainly due to their adjustable speed characteristic and now affect the dynamics of the system. The DFIG based WECS, also called as the Improved Variable Speed WECS, is currently the maximum used by the wind industry. DFIG has the ability to optimize wind power from a wide-ranging wind speed that fixed speed induction generators cannot. The DFIG is a slip ring induction generator and the stator windings are directly connected to the mains through a constant frequency phase and the rotor windings are connected to a reverse voltage converter (AC-AC). This system allows large-scale variable speed operation; the behavior of the generator is controlled by the electronic power converter and its controllers. The power electronics converter includes two IGBT converters, the rotor side converter and the grid side converter, which are connected to an intermediate circuit capacitor. The rotor side converter controls active and reactive power flow through the generator, and the grid side converter controls the intermediate circuit voltage to a constant value and ensures operation with a high power factor. The output power of the stator always flows in the network. The size of the converter is not related to the total power of the generator but to the selected speed variation range, typically a range of ± 30% around the synchronous speed. Therefore, the size and power rating of the drive is proportional to the slip power

The WRIM model expressed in a d-q reference frame rotating at synchronous speed is obtained by considering the position of the axis as shown in the figure. 4.3 is shown at an angle rotating synchronously to the D-axis. The rotor phase coil is σ ahead of the axis of the stator phase a coil. Let ωs be the synchronous speed with which d-q axis rotates.

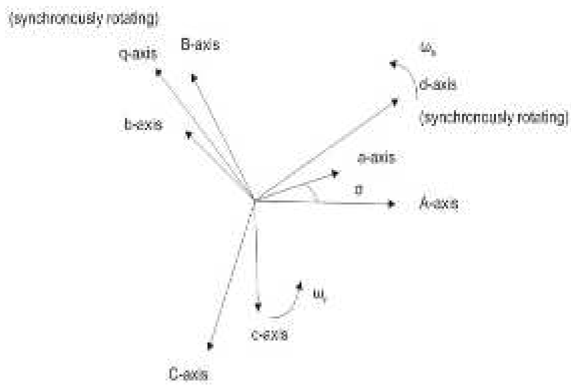

Figure 2 Schematic of axis transformation (ABC to dq)

The matrices are

$$Ms=\frac{2}{3}\begin{bmatrix}\cos(\sigma) & \cos(\sigma-2\pi/3) & \cos(\sigma-4\pi/3)\\ -\sin(\sigma) & -\sin(\sigma-2\pi/3) & -\sin(\sigma-4\pi/3)\\ 1/2 & 1/2 & 1/2\end{bmatrix}$$

$$M_r=\frac{2}{3}\begin{bmatrix}\cos(\sigma_s-\sigma) & \cos((\sigma_s-\sigma)-2\pi/3) & \cos((\sigma_s-\sigma)-4\pi/3)\\ -\sin(\sigma_s-\sigma) & -\sin((\sigma_s-\sigma)-2\pi/3) & -\sin((\sigma_s-\sigma)-4\pi/3)\\ 1/2 & 1/2 & 1/2\end{bmatrix}$$

Here the subscript 's' denotes stator quantity and 'r' represents rotor quantity and all the rotor quantities are referred to the stator.

$$v_{ds}=r_s i_{ds}+\frac{d}{dt}\varphi_{ds}-\omega_s\varphi_{qs}$$

$$v_{qs}=r_s i_{qs}+\frac{d}{dt}\varphi_{qs}+\omega_s\varphi_{ds}$$

$$v_{dr}=r_r i_{dr}+\frac{d}{dt}\varphi_{dr}-(\omega_s-\omega_r)\varphi_{qr}$$

$$v_{qr}=r_r i_{qr}+\frac{d}{dt}\varphi_{qr}+(\omega_s-\omega_r)\varphi_{dr}$$

$$\varphi_{ds}=L_s i_{ds}+L_m i_{dr}$$

$$\varphi_{qs}=L_s i_{qs}+L_m i_{qr}$$

$$\varphi_{dr}=L_r i_{dr}+L_m i_{ds}$$

$$\varphi_{qr}=L_r i_{qr}+L_m i_{qs}$$

The dynamic model of induction machine in synchronous reference frame is shown in Figure 2.

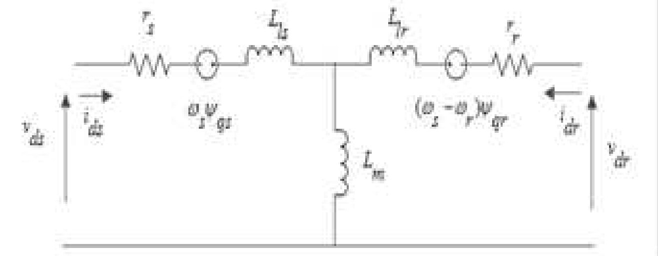

Figure 3 D-axis equivalent circuit of WRIM

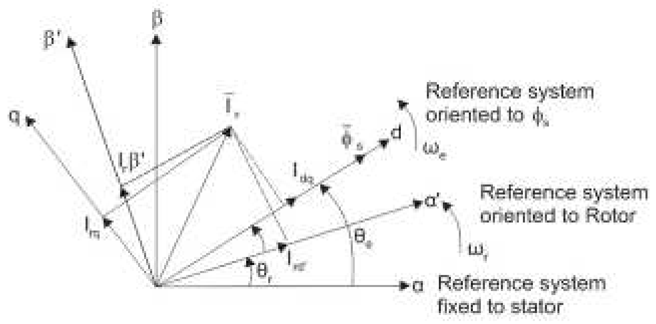

Figure 4 Reference system used in DFIG

From the above phasor diagram current relation can be written as:

$$\bar{I}_r=\bar{I}_{r\alpha}+\bar{I}_{r\beta}$$

$$\bar{I}_r=\bar{I}_{rq}+\bar{I}_{rd}$$

The total voltage is expressed as an algebraic sum of d-axis and q-axis component as:

$$\bar{V}=\bar{V}_d+j\bar{V}_q\,.$$

The rotor and stator equations when combined gives the equivalent circuit. Therefore, we have the following DFIG equivalent circuit and as:

$$\bar{V}_{s,dq}=\bar{i}_s R_{s,dq}+\frac{d\,\bar{\phi}_{s,dq}}{dt}+j\omega_s\phi_{s,dq}$$

$$\bar{V}_{r,dq}=\bar{i}_r R_{r,dq}+\frac{d\,\bar{\phi}_{r,dq}}{dt}+j(\omega_s-\omega_r)\phi_{r,dq}$$

Where, $\bar{\phi}_{r,dq}=L_r i_{r,dq}+L_m i_{s,dq}$ and

$$\bar{\phi}_{r,dq}=L_r i_{r,dq}+L_m i_{s,dq}\,.$$

$$L_s=L_m+L_{ls}$$

$$L_r=L_m+L_{lr}$$

$$\bar{i}_{m,dq}=\bar{i}_{s,dq}+\bar{i}_{r,dq}$$

Where the d-q are the axis of stator flux reference system $\bar{V}_{s,dq},\bar{i}_{s,dq},\bar{\phi}_{s,dq}\ \&\ \bar{V}_{r,dq},\bar{i}_{r,dq},\bar{\phi}_{r,dq}$ are the stator & rotor voltage, current and flux vector $\omega_s and\omega_r$ are the stator flux and rotor electrical speed.

The Apparent power at the DFIG is as follow

$$\bar{S}=\bar{V}_s\bar{i}_s^{*}+\bar{V}_r\bar{i}_r^{*}$$

Stator and rotor feed voltage vectors are given by:

$$\bar{S}=\bar{i}_s^{*}(R_s\bar{i}_s+\frac{d\phi_s}{dt}+j\omega_s\phi_s)+\bar{i}_r^{*}(R_r\bar{i}_r+\frac{d\phi_r}{dt}+j\omega_r\phi_r)$$

The changes in the magnetic flux equation shown in above equation can be neglected in stationary mode and so, $\frac{d\phi_s}{dt}$=0 and $\frac{d\phi_r}{dt}$=0.Substituting the values of stator and rotor flux we have:

$$\phi_s=L_s i_s+L_m i_r$$

$$\phi_r=L_r i_r+L_m i_s$$

$$\bar{S}=\{(R_s+L_m\bar{I}_r)I_s^{*}+(L_r\bar{I}_r+L_m\bar{I}_s)I_r^{*})]-j\omega(L_m\bar{I}_s+L_r\bar{I}_r)\bar{I}_r{}^{*}\}$$

But,

$$s = \frac{\omega_r}{\omega_s};$$

$$\bar{S} = \{(R_s + j\omega L_s)|\bar{I}_s|^2 + (R_r + js\omega L_r)|\bar{I}_r|^2 + js\omega L_m \bar{I}_s \bar{I}_r^* + js\omega L_m \bar{I}_r \bar{I}_s^*\}$$

An equation representing active and reactive DFIG power is obtained as:

$$P_g + jQ_g = \frac{3}{2} j\omega_s L_m (I_{sd} - jI_{sq})(I_{rd} + jI_{rq}) + \frac{3}{2} js\omega_s L_m (I_{sd} + j\ldots$$

On further resolving above equation, we get:

$$P_g + jQ_g = \frac{3}{2} j\omega L_m \{[(I_{sd} I_{rd} + I_{sq} I_{rq}) + j(I_{rq} I_{sd} - I_{rd} I_{sq})] + s[(I_{sd} I_{rd} + I_{sq} I_{rq}) + j(I_{sq} I_{rd} - I_{sd} I_{rq})\}$$

Which on further resolving we get the DFIG active and reactive power as

$$P_g = \frac{3}{2}\omega_s L_m (1 - s)(I_{rd} I_{sq} - I_{rq} I_{sd})$$

$$Q_g = \frac{3}{2}\omega_s L_m (1 + s)(I_{rd} I_{sd} + I_{rq} I_{sq})$$

The real and reactive stator and rotor powers for the DFIG are given by:

$$P_s = \frac{3}{2}(V_{ds} i_{ds} + V_{qs} i_{qs})$$

$$Q_s = \frac{3}{2}(V_{qs} i_{ds} - V_{ds} i_{qs}) \quad P_r = \frac{3}{2}(V_{dr} i_{dr} + V_{qr} i_{qr})$$

$$Q_r = \frac{3}{2}(V_{qr} i_{dr} - V_{dr} i_{qr})$$

The torque of induction generator is shown by:

$$T = p\frac{P_g}{\omega}$$

Thus,

$$T = \frac{3}{2} p L_m (I_{rd} I_{sq} - I_{rq} I_{sd})$$

RESULTS

A hybrid microgrid whose parameters are given in Table 4.1 is simulated using the MATLAB/SIMULINK environment. The operation is performed for network connected mode. The photovoltaic system performance of a double fed induction generator, with a hybrid microgrid, is analyzed. Solar radiation, cell temperature and wind speed are also taken into account for the study of hybrid micro grids.

The response to wind speed, three-phase stator voltage and three-phase rotor voltage are shown in Figures 5-6. Here, the value of wind speed varies between 1.0 and 1.05 pu, which is essential for the performance study of double-fed induction generator. The phase-to-phase stator voltage is set to 300 V, while the rotor voltage value is 150 V.

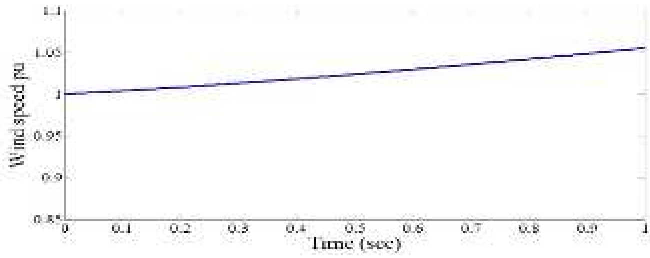

Figure 5. Response of wind speed

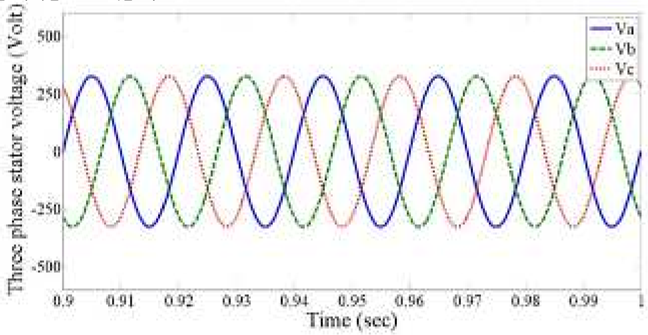

Figure 6. Three phase stator voltage

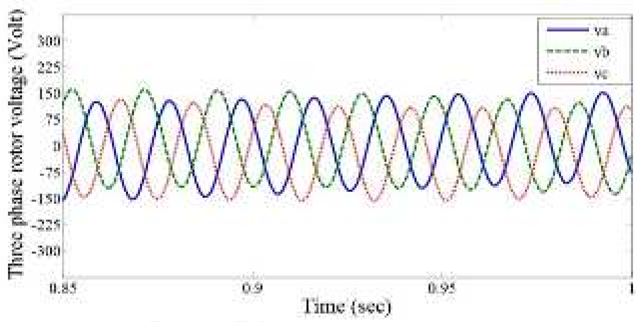

Figure 7. Three phase rotor voltage

The various characteristics of a hybrid microgrid are shown in Figure 8-9. Here the microgrid works in grid connected mode. In this mode, the mains converter operates in PQ mode and the power is balanced by the mains. Battery is fully charged. The mains maintain the AC bus voltage and the mains converter maintains the DC bus voltage. Figure 8 shows the solar irradiance level curve that is established at 950 W/m2 from 0.0 s to 0.1 s, linearly increases at 1300 W/m2 from 0.1 s to 0.2 s, remains constant at 0.3 s to 0.4 s decreases to 950 W/m2 and maintains that value for 1 s. Figures 10 and 11 mean the output voltage, current and power with respect to the solar radiation signal. The output power of the photovoltaic panels varies from 11.25 kW to 13 kW, which closely follows solar irradiance when the ambient temperature is constant.

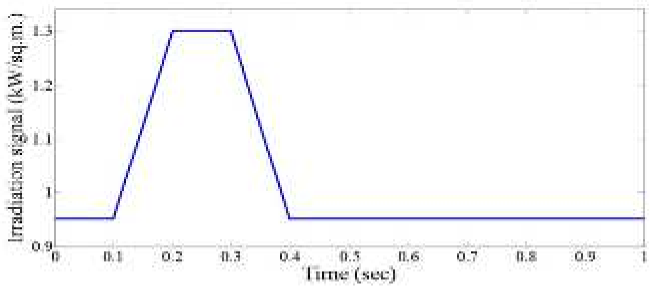

Figure 8. Irradiation signal of the PV array

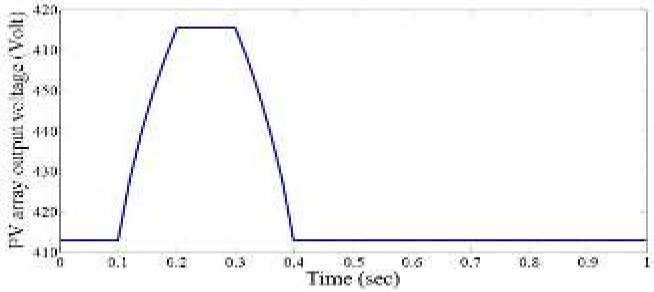

Figure 9. Output voltage of the PV array

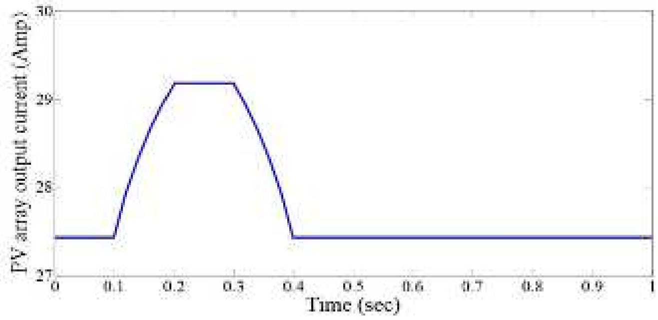

Figure 10. Output current of the PV array

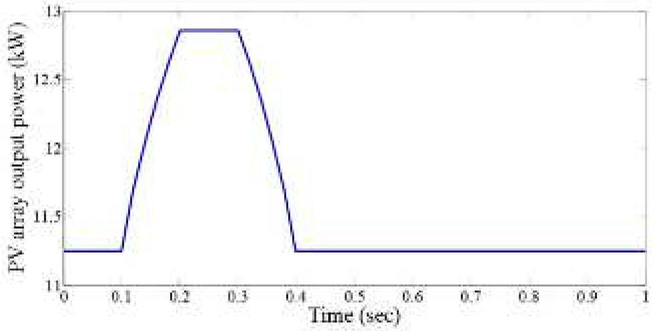

Figure 11. Output power of the PV array

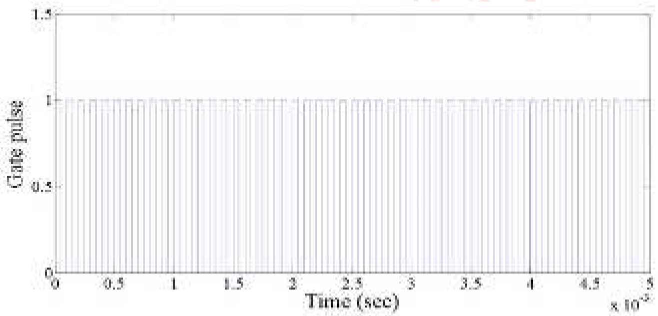

Figure 12. Generated PWM signal for the boost converter

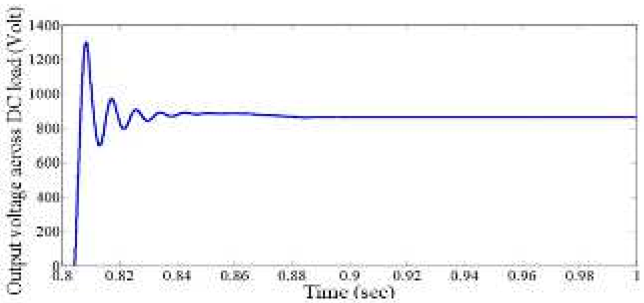

Figure 13. Output voltage across DC load

Figure 12. Gate pulse signal being fed to the boost converter switch. The output voltage at the DC load is set to approximately 820V, as shown in Figure 13.

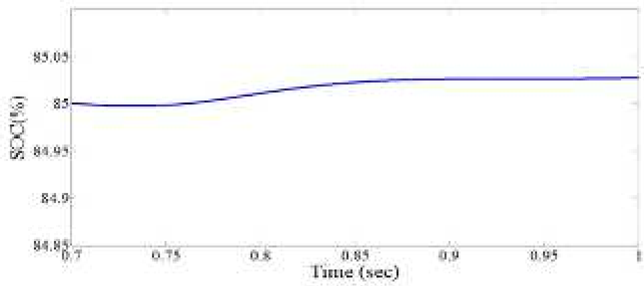

Figure 14. State of charge of battery

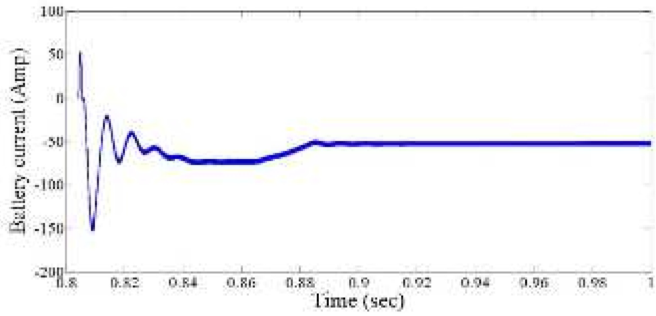

Figure 15. Current of battery

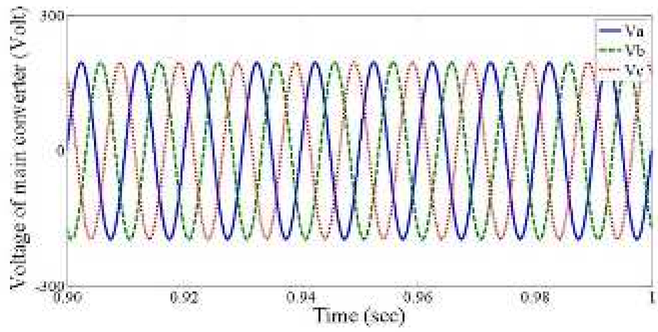

Figure 16. AC side voltage of converter

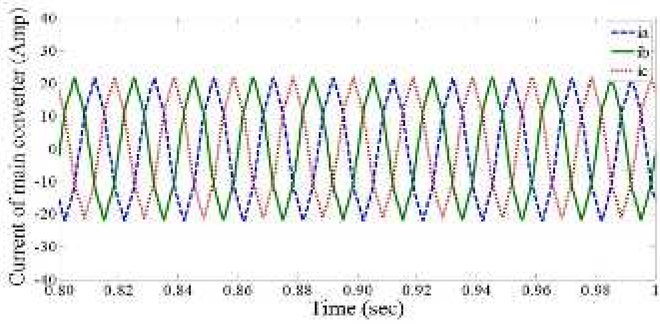

Figure 17. AC current of converter

Battery characteristics are shown in Figures 14 and 15. The state of charge of the battery is set to 85%, while the battery current varies between -50 and 50A and the battery voltage value is approximately 163.5. The output characteristics of voltage and current of an AC load are depicted by above figure. The value of phase-to-phase voltage of an AC load is 300 V and the value of current is 50 A. Figure 16 and 17 shows the voltage and current response on the AC side of the main converter when the solar irradiance value varies between 950 and 1300 W/m2 with a fixed 25 kW DC load.

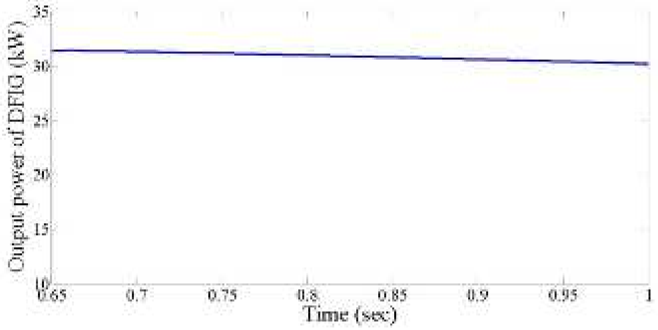

Figure 18. Output power of DFIG

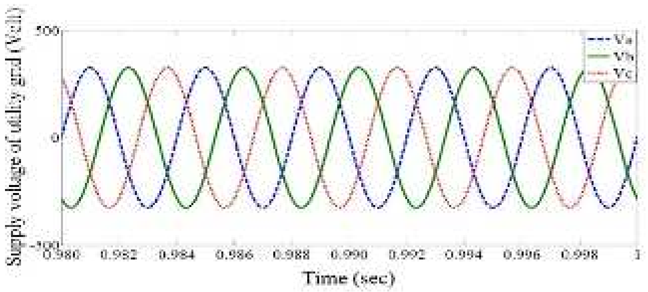

Figure 19. Three phase supply voltage of utility

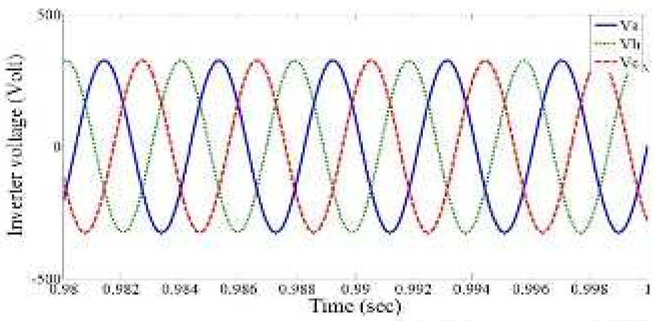

Figure 20. Three phase inverter voltage

Figure 19 shows the output power response of the DFIG converted to a constant value of 32kW due to mechanical inertia. Figure 20 represents the three-phase supply voltage to the public grid and the output voltage of a three-phase PWM inverter, respectively.

CONCLUSION

Modeling of hybrid microgrid is done in MATLAB/SIMULINK environment for power system configuration. The present work mainly covers the network operation mode of hybrid network. Models have been developed for all converters to maintain a stable system under various load and source conditions, and the control mechanism has also been studied. MPPT algorithms are used to optimize power utilization from DC sources and to coordinate power exchange between DC and AC grids. Although hybrid networks can reduce the DC/AC and AC/DC conversion processes to a single AC or DC network, there are many practical problems for the implementation of hybrid networks based on current AC-dominated infrastructure. The efficiency of the overall system depends on the reduction of conversion losses and the addition of an additional intermediate circuit. Hybrid grids can supply consumers with reliable, high-quality and more efficient electricity. Hybrid networks may be viable for small isolated industrial installations with photovoltaic systems and wind turbines as the main source of energy. Additional simulation and monitoring is possible in transition mode based on the analysis performed in the job. The suggested hybrid microgrid can be scaled from multiple sources and energy storage devices such as super capacitors and batteries can be used. Unit values can be used in place of actual values.

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ISSN: 2456-6470